

# Preliminary Estimates of Volume Transport and Variability at Windward Passage from Shipboard Measurements

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## Introduction

The Windward Passage separates the islands of Cuba and Hispaniola in the northern Caribbean Sea. Historically, few direct volume transport measurements exist for the passage, forcing scientists to use indirect estimates when studying Caribbean transport pathways and attempting to compute water mass budgets for the region (Johns et al., 2002). In 2003, the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) and NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML) began a targeted research study of Windward Passage and the surrounding region to resolve the mean current flow through the passage and to gain a better understanding of the transport variability associated with the flow. As part of this project, entitled the Windward Passage Experiment, a moored array was deployed across the passage, and four regional hydrographic surveys were conducted. Data gathered from lowered and hull-mounted instrumentation during these surveys are helping to resolve the vertical and horizontal structure of the inflow through the passage and being incorporated with data from the moored array to calculate new volume transport estimates. Additionally, these data are providing insight on the pathways by which Atlantic inflow is delivered to the passage through the southern Bahamas.

## Motivation

The Florida Current and the Gulf Stream system have been studied more extensively than any other current system in the Atlantic Basin (Schmitz, 1996). The role of this system both as a return pathway for the Sverdrup flow from the North Atlantic subtropical gyre and as the upper western boundary component of the Meridional Overturning Cell (MOC) is well-documented (Schmitz and Richardson, 1991). Numerous Florida Current transport measurements at 27°N provide a well-established mean transport of ~32 Sv ( $1 \text{ Sv} = 10^6 \text{ m}^3/\text{s}$ ) (Baringer and Larsen, 2001).

The Florida Current is fed via Atlantic inflow through the Caribbean passages. The net inflow exits the Caribbean through the Yucatan Channel into the Gulf of Mexico, ultimately entering the Straits of Florida as the Florida Current. The current is then augmented

with flow from Old Bahama Channel and Northwest Providence Channel as it translates northward through the Straits. In contrast to the depth of research focused on the Florida Current, far fewer measurements of Atlantic inflow into the Caribbean have been conducted. Only recently have field studies provided direct measurements of flow through the Caribbean's Greater Antilles and Lesser Antilles passages using modern techniques (Johns et al., 2002). These data have served to quantify mean transport values and describe the distribution of Atlantic inflow into the Caribbean. Combined measurements of Stalcup and Metcalf (1972), Metcalf (1976), and Wilson and Johns (1997) show a total Caribbean inflow of ~28 Sv, with ~18 Sv entering through the Lesser Antilles passages, and ~10 Sv coming in through the Greater Antilles passages.

Of the two Greater Antilles passages, direct transport measurements at Mona Passage, between Puerto Rico and Hispaniola, demonstrate a mean flow of ~3 Sv. The remaining 7 Sv are indirectly estimated for Windward Passage by differencing transports measured at the other passages studied (Johns et al., 2002). As previously mentioned, one of the goals of the Windward Passage Experiment is to replace this estimate with a more accurate mean transport value based on direct observations.

## Methodology

During the study, a moored array consisting of five current meter moorings, two inverted echo sounders (IES), and two shallow pressure gauges were deployed along the sill of Windward Passage. The array was deployed for a 17 month period, from October 2003 through February 2005.

Concurrent with this moored deployment, four hydrographic surveys of the region were conducted. During each cruise, repeat hydrographic stations were occupied and full water column measurements of conductivity, temperature, depth, dissolved oxygen, and velocity were collected using an instrumentation package equipped with a Sea-Bird 9plus CTD+O<sub>2</sub> and 24 bottle rosette water sampler, a lowered downward-looking 150 kHz RD Instruments (RDI) broadband acoustic Doppler current profiler (LADCP), and an

upward-looking 300 kHz RDI Workhorse LADCP (cruises 2-4 only). Stations were located along sections at Windward Passage and passages *upstream*, including passages between Cuba and Great Inagua, and Haiti and Great Inagua, and selected passages through the southern Bahamas and Turks and Caicos. Sections were also established *downstream* of Windward Passage across the axis of the Cayman Basin at two locations.

During each survey, continuous current velocity measurements of the near-surface flow were made with hull-mounted ADCP instrumentation (cruises 1 and 4: RDI 150 kHz broadband ADCP and RDI 38 kHz Ocean Surveyor ADCP; cruises 2 and 3: RDI 150 kHz narrowband ADCP), and continuous measurements of surface temperature and salinity were recorded from the ship's thermosalinograph flow-through system. Additionally, Lagrangian drifting buoys were deployed during three of the surveys (cruises 2-4).

## Initial Results and Future Work

During each of the 4 occupations of Windward Passage, initial volume transport calculations derived from LADCP data collected at 14 stations across the passage were lower than the previously estimated 7 Sv inflow. Of the 4, the largest inflow (~6.5 Sv) was recorded during the first survey in October of 2003. The flow structure through the passage is shown below (Figure 1). In the section, a strong surface jet at the western side of the passage can clearly be seen entering the Cayman Basin. Upstream LADCP sections and hull-mounted ADCP data also confirm this jet, showing its southeastward flow along the northeast coast of Cuba towards Windward Passage. At the deepest part of the

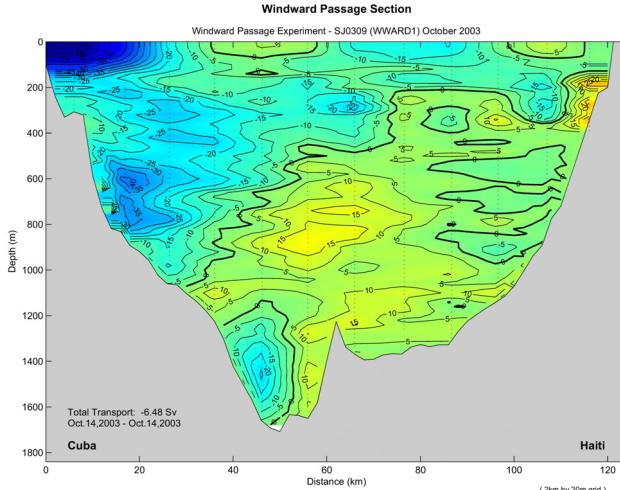


Figure 1. Windward Passage velocity section, October 14, 2003. Negative values (shown in blue) represent inflow.

sill, centered around 1500m, upper North Atlantic Deep Water (uNADW) can be seen flowing into the basin. This uNADW, diverted from the Atlantic Deep Western Boundary Current (DWBC) through deep passages in the southern Bahamas, flows southeastward just north of Windward Passage between Great Inagua and the Greater Antilles, presumably to rejoin the DWBC north of Puerto Rico. The core of the flow appears to be centered at a depth of 1500-1600m (confirmed by upstream LADCP sections on multiple surveys). With a sill depth maximum of 1670m, Windward Passage provides a pathway for a small portion of this flow to enter the Cayman Basin and the Caribbean. LADCP data from cruises 2-4 show much smaller volume transports at Windward Passage due to eddies present in the passage during the surveys.

LADCP current velocities collected during this study will be improved through the incorporation of hull-mounted ADCP data. These improved velocities will be used in conjunction with CTDO<sub>2</sub> data to quantify the volumes of the different water masses present in the passages studied. These results will be used for comparison and validation of the moored data set.

## References

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